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(54) Data transmission system

(57) This relates to a data transmission system, especially for remote control application in difficult environmental conditions, in which the transmission medium is a closed loop arrangement which interconnects the master station and the substations of the system. Data is conveyed in digital form, using a radio frequency carrier with frequency shift keying, each data message including an address code identifying the station for which the message is intended.

The substations are capacitively coupled to the loop conductors, the values of the capacitors being so chosen that the couplings are low impedance at the carrier frequencies and high impedance for the usual mains frequencies.

As described, a screened cable comprising three pairs is used, one pair P for power, one CP for clock, and one DP for data signals.

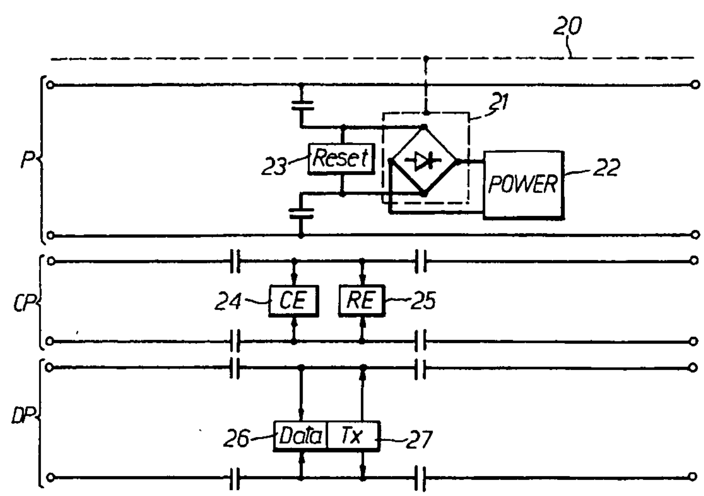

Fig. 3

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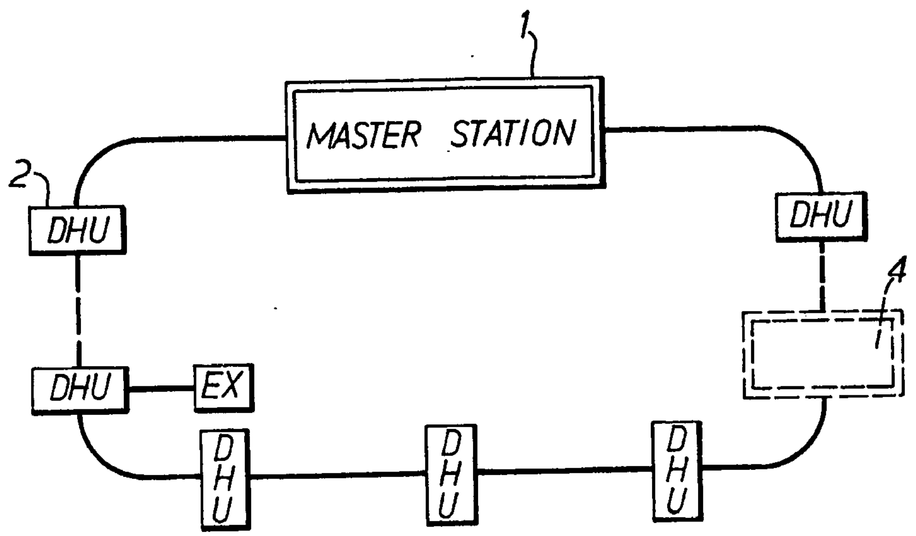
1
MASTER STATION
2
DHU
DHU
4
DHU
EX
DHU
DHU
DHU

Fig. 1

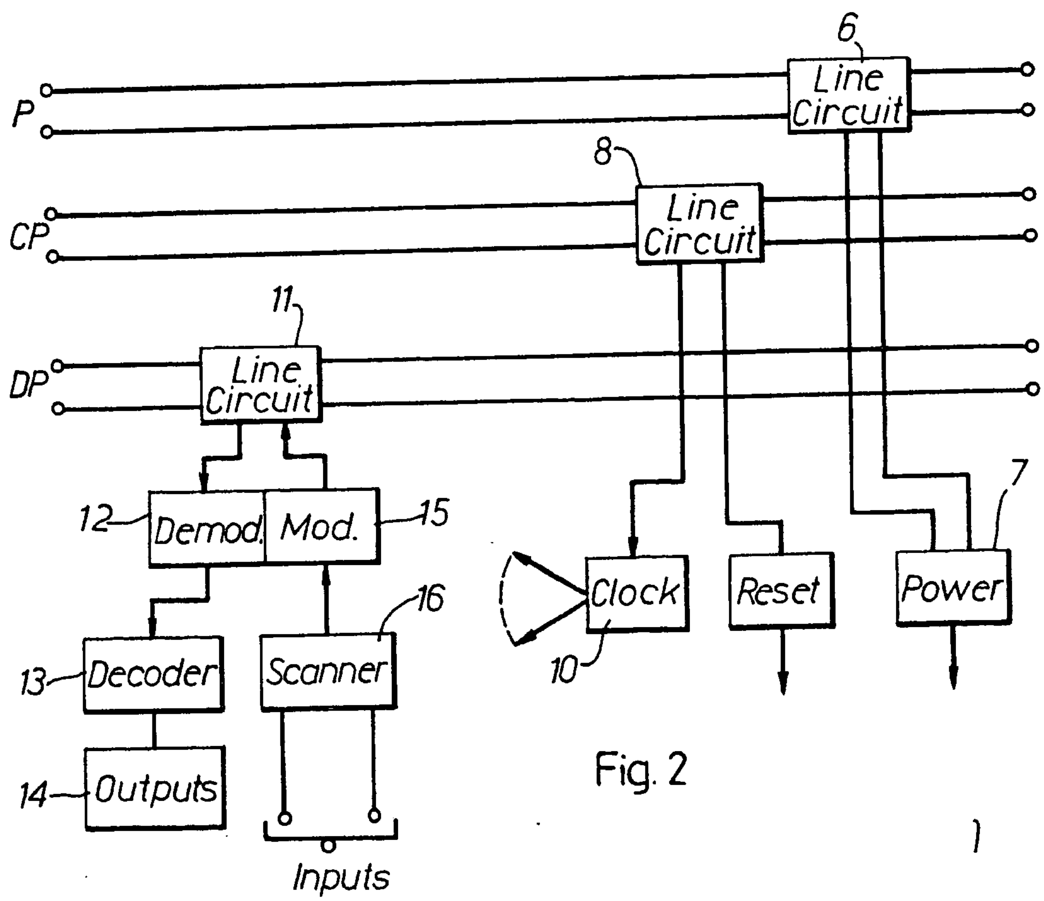
6
Line Circuit
P
8
Line Circuit
CP
11
Line Circuit
DP
12
Demod.
Mod.
15
7
Clock
Reset
Power
10
13
Decoder
Scanner
16
14
Outputs
Inputs

Fig. 2

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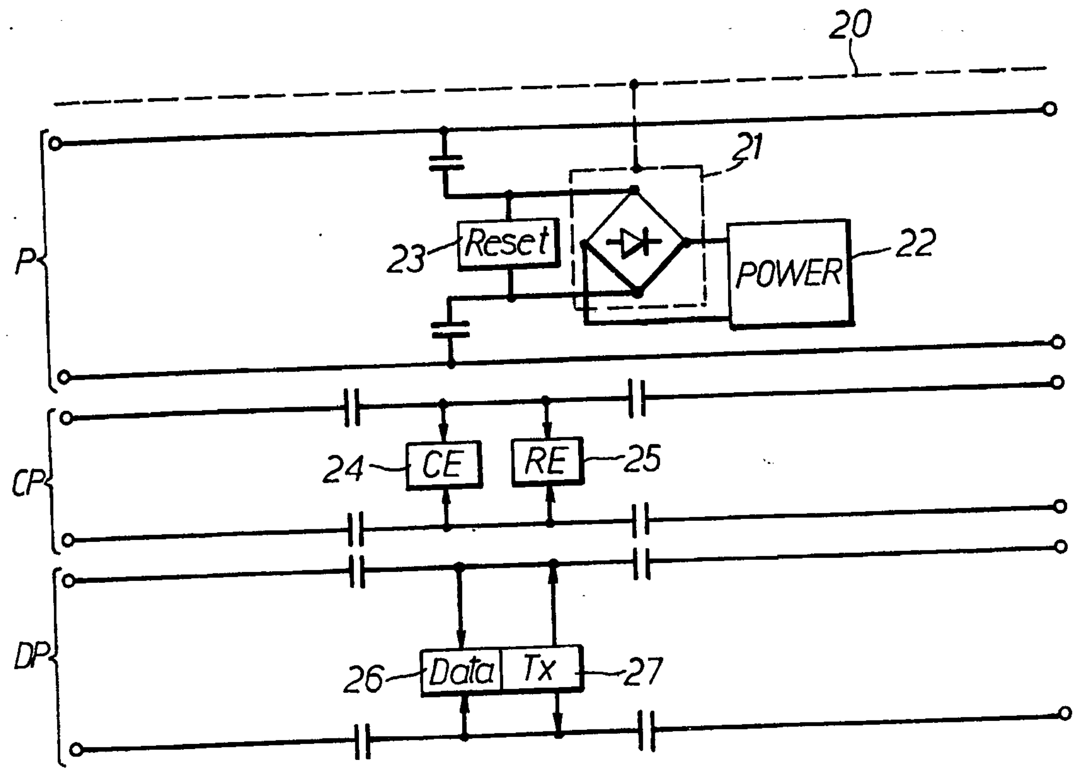

Fig. 3

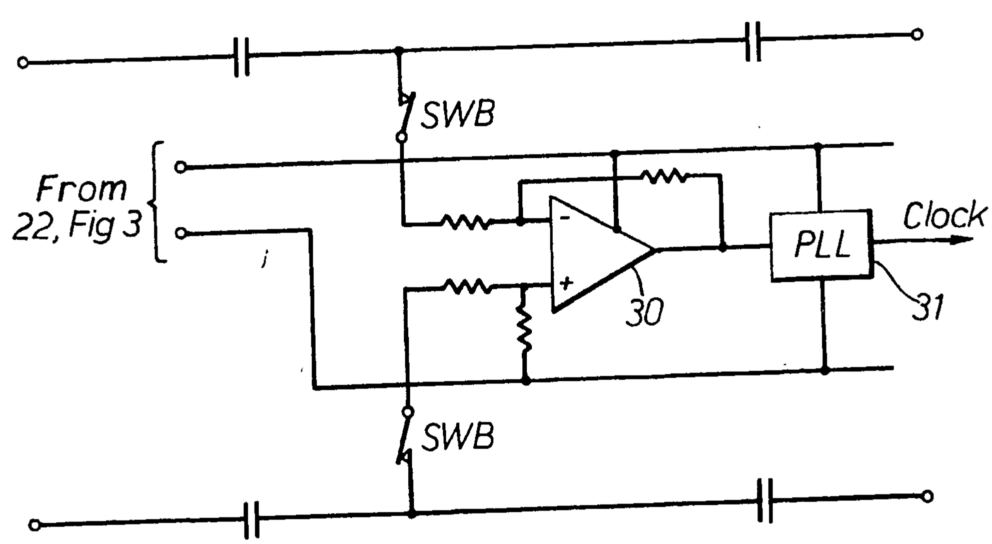

Fig. 4

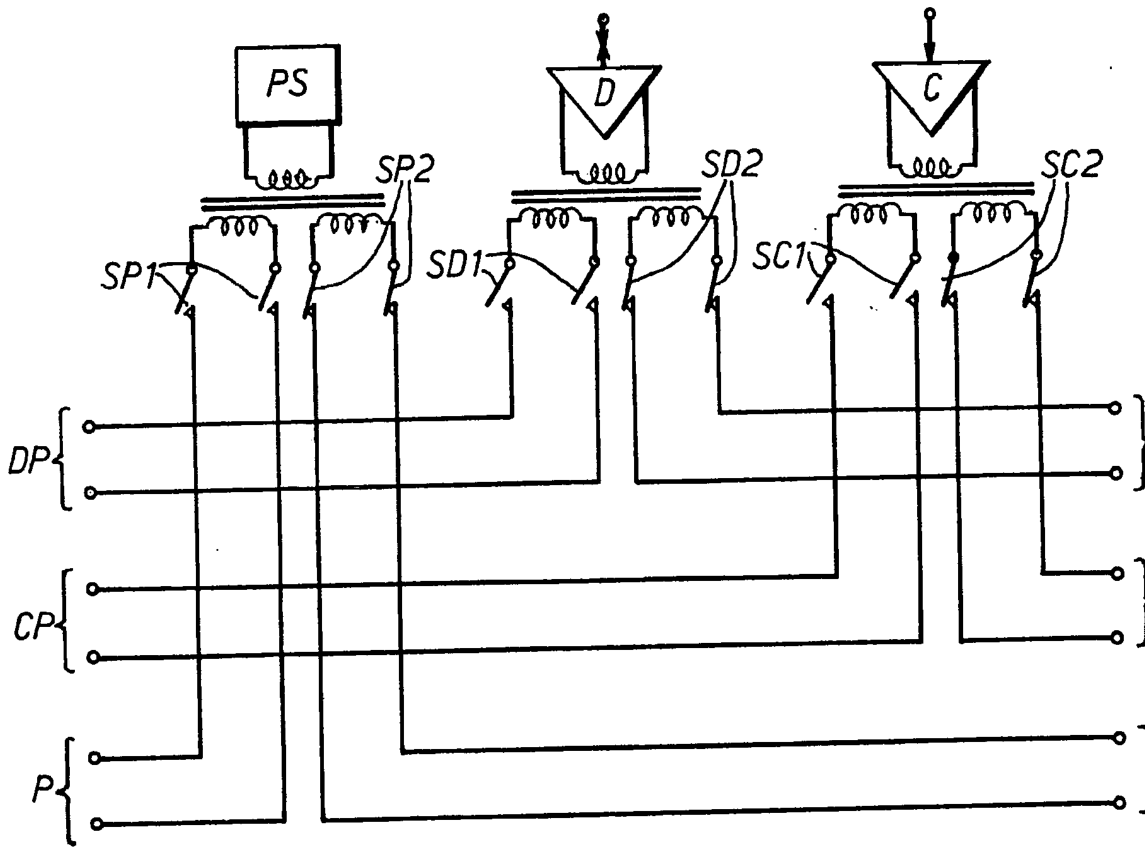

Fig. 5

SPECIFICATION

Data transmission system

This invention relates to a data transmission system for use for remote control and/or monitoring of remote devices.

Such a system in which relatively large number of substations is used tends to be complex if each substation has to be individually coupled to its master station. Hence systems have been designed in which the master station, the substations and intersubstations are inter-connected by a single closed loop data transmission system. However, the use of such a single loop arrangement has the disadvantage that the system is vulnerable to breaks or short-circuits in the transmission system. Hence it is desirable in such a system to provide means for minimising this vulnerability.

According to the invention there is provided a data transmission system, which includes a master station and a number of sub-stations inter-connected by a data highway, in which the data is transmitted as modulations on an alternating current carrier, each data message including an appropriate address code, in which each said sub-station is capacitively coupled to the data highway, and in which data transmission over the highway can be effected in either direction.

The actual system to be described below is a closed-loop system, in which both ends of the data highway are connected to the master station. However, it will be appreciated that the invention is not limited to such a system.

Hence the present invention further provides a data transmission system, which includes a master station and a number of sub-stations interconnected by a closed loop data highway, in which the data is transmitted as modulations on an alternating current carrier, in which both ends of the loop are connected to the master station, the master station interrogating the sub-stations cyclically in search of stations with data for transmission, in which when the interrogated sub-station has data to be sent to another station, the message sent from the interrogated sub-station to convey that data includes an address code identifying the station to which that message is to be sent, in which each said sub-station is capacitively coupled to the data highway; and in which transmission over the loop, whether for said interrogations by the master station or for the transmission of a message in response to a said interrogation, can be in either direction over the closed loop highway.

An embodiment of the invention will now be described with reference to the accompanying drawings in which:-

Figure 1 is an overall block diagram for a remote control/monitoring system to which the present invention is applicable.

Figure 2 shows schematically the arrangement of the line circuits associated with one of the substations of the system.

Figure 3 shows schematically how the various line circuits at a substation are coupled to the line loops.

Figure 4 is a block diagram indicative of the line circuit which couples the P loop shown in Figure 3 to a substation.

Figure 5 shows schematically the master station line network used in the system of Figure 1.

The system shown in Figure 1 was developed for use in a warship, where environmental conditions are difficult, and where system integrity is essential. This means that the system must be, to some extent, fault tolerant in that no one fault will put the system out of commission. In addition, when a fault does occur it must be readily and rapidly detectable. These criteria led to the choice of a closed-loop system with a master station 1 and a number of substations, also known as data handling units, such as 2. Each substation has a number of individual devices to be controlled, and also devices whose conditions or positions are to be reported to the station 1. Where the number of devices served by a substation exceeds that servable by a standard substation, that substation has an extender, such as the extender 3. The system can also, if desired, include a standby master station 4, which is normally switched out of circuit, but which is brought into circuit if the master station 1 fails. The master station contains its own system checking arrangements, also known as a "watchdog", and if there are more than one master stations each has its own watchdog.

The system shown caters for a number of substations such as 2 each of which, as indicated above, deals with a number of devices to be controlled or whose condition is to be monitored. The stations are interconnected by a six-core loop highway cable, which contains three twisted pairs. One pair is used to convey power, a second pair is used to convey the systems clock pulses and also reset signals when such are needed, and the third pair is used to convey the data signals. Data transmission uses alternating current in the range of 20 KHz to 100 KHz, with frequency shift keying (FSK) as the preferred modulation technique.

In the normal method of operation of the system the master station 1 generates messages successively with each message containing the address of one of the substations such as 2. On reception at the substations, and it will be appreciated that each message reaches every one of the substations, the address is decoded and if the message is for that substation, its contents are passed to a decoder from which it reaches the device in question. Data from the monitored devices at that substation can then be transmitted to another station. This data is received by another substation whose address is included in the message. At the destination substation the message is decoded, and if checks show that it is correct, it may generate an instruction to change the state of a device identified in the message, e.g. to switch it on or off, or a request for an indication of its condition.

Thus if a substation has a message to send, either to the master station or to another substation, it sends this message when it is interrogated in the course of the cyclic operation referred to above. Such a method of enabling the stations to send is often called a polling system. The speed of opera-

tion, and the number of bits in each message, are such that all devices are interrogated at least one per second.

The master station 1 performs the following functions:-

(a) control of data transactions between substations;

(b) generation of addressess;

(c) allocation of data transmission priorities;

(d) detection, correction and display of fault conditions;

(e) distribution of power;

(f) checking of data integrity;

A substation performs the following functions:-

(i) interfacing with the outside environment, i.e. the devices to be controlled and/or monitored;

(ii) collecting and transmitting data in the form of command or monitor signals.

(iii) receiving and outputting control and display data.

The functions of the three pairs which form the data highway will now be explained, see Figure 2, which shows how each substation is connected to the three pairs which form the highway. The first highway is used for the transmission of power to all substations, at each of which the power is extracted via a line circuit 6 one of which is needed on each cycle of operation. Reset signals are also sent, as will be seen below, when faults are detected, and can be extracted from the highway via the line circuit 6. As will be seen below, the circuitry 7 associated with the line circuit 6 includes reset signal extraction as well as power extraction.

The second pair CP is used to convey the system's clock pulse train, so that the system is maintained in overall synchronism, and also to convey reset signals. Its line circuit 8 feeds a reset signal extraction circuit 9 and a clock circuity block 10.

The third pair, the Data Pair DP conveys the data messages, the conveyance of which is the raison d'etre of the entire system. The line circuit 11 for this pair is connected to a demodulator 12, which in turn feeds a decoder 13 via which incoming commands are passed to the outputs 14. Also associated with the line circuit 11, we have a modulator 15, which receives outgoing messages from the substation inputs via a scanner 16, and passes them to the line circuit 11 for transmission. Note that different base frequencies are used on the highway pairs.

We now consider Figure 3, which shows how the line circuits shown in Figure 2 are connected to the respective pairs. Here the line circuits for the substation's power pair P, the clock CP and the data pair DP are respectively represented by the blocks shown with reset connections provided for the pairs P and CP.

For each pair, its two wires are capactively coupled to the line circuit via two or four capacitors as shown. Thus the line circuits for the pairs CP and DP, plus the capacitors, are each H networks. The values of the capacitors are so chosen that the capacitive coupling is high impedance for low frequencies such as the normal low frequency mains supplies, but are low impedance in the range of frequencies, 20 KHz to 100 KHz used for the data transmission. This low impedance is used to develop a signal under conditions in which cable shorting occurs.

The pairs are screened twisted wire pairs and the screen is indicated at 20. The power pair P is coupled via two capacitors to the rectifier circuitry 21, earthed to the screen as indicated, which feeds the remainder of the power circuitry 22. Also fed via the capacitors is a reset detector and extraction circuit 23. The clock pair CP is connected, via capacitors an shown to a clock extraction circuit 24 and reset detection and extraction circuit 25. The data pair DP is similarly connected to its circuits, in this case shown schematically as a data reception block 26 and transmitter 27.

In Figure 4 which shows the main elements of the clock line circuit, 8 of Figure 1, the line is connected via contacts SWB to an operational amplifier 30 which in turn feeds a phase-locked loop cicuit 31 whose output provides the clock pulses to the entire circuit.

The power for the circuitry of Figure 4 comes from the power supply unit 22 (Figure 3), which is connected across the power line as shown in Figure 3. This unit 22 also supplies power to the rest of the substantion.

The data line circuit is in essence identical to the clock line circuit shown in Figure 4. Its output feeds the demodulation circuitry 12, Figure 2, while the output from the modulation circuitry 15 is connected to the line wires on the "Inside" of the capactive couplings.

Figure 5 shows in simplified form how the master station circuitry is connected to the loop pairs. Each of the output/input line circuits and is transformer coupled to the pairs, with contacts included in each such connection. The power source PS is similarly transformer coupled to the power pair P. Under the normal conditions of operation the master station is only connected to one end of the loop, i.e. the contacts SP1, SR1 and SC1 are closed while SP2, SR2 and SC2 are open or we have the condition shown in which SP1, SR1 and SC1 are open while SP2, SR2 and SC2 are closed.

In the line circuits for the pairs D and C the alternating current is in the relatively high frequency band mentioned above, with different frequencies used for the clock and data pairs and a lower frequency used the power pair. That is, a rectifier bridge in the power line circuits (see Figure 3) rectifies from the relatively low frequency referred to. In one case the power carrier is 400 Hz, the data carrier is 40 KHz, and the clock carrier is 60 KHz, with frequency shift keying used. The frequency shift used is 5 KHz. Thus the capacitors are low impedance for the carriers used in the system, but (as already mentioned) high impedance for the more usual mains frequencies.

We now describe a typical data transaction between two of the substations. A command is input at one of the substations by the operation of a switch therein which identifies the data to be sent and the station, either substation or master station, to which that data is to be sent. Hence the data, in this case a one-bit signal which calls for, e.g. a relay operation, is accompanied by a code which identifies the

destination for that signal. When the master station, in the course of its cyclic interrogation or polling, sends the address code for the station with a message to be sent, that interrogation message is decoded in that station. The presence of a signal to be sent causes the transmission of that signal, prefixed by the destination station's address.

In the "called" station, the decode circuitry 13, Figure 2, responds to the code for the relay or other device to be controlled and passes the accompanying signal to the output block 14. This causes the device to be controlled to take up the desired condition.

Data flow can take place between any pair of substations, or between master station and a substation, under control of the master station. The latter includes a sequencer circuit which controls the successive timed transmissions of the substations addresses with the time period between two such addresses being adequate either for the transmission of a message from the master station to the addressed substation, or for the transmission of a message from the addressed substation to another substation.

Spare contacts of the relay to be controlled in the manner just described can be connected to an input circuit of the relay's substation to cause the switching on of a lamp in a control panel connected to a substation (or the master station) somewhere on the highway.

The address as received from the line at a substation is an eight-bit word the five most significant bits of which are the substation's address. When they are decoded a sequencer in the scanner block 16 steps through the devices to be controlled, whose inputs as "seen" by the scanner are on up to four input cards each scanning up to eight devices. The messages as sent from the substation called by the master to another substation each consists of a sixteen-bit message comprising:-

(i) The five bit address of the station for which the message is intended.

(ii) Two bit address to identify the input card.

(iii) One parity fault bit.

(iv) An eight-bit data word which includes the conditions of the eight input circuits on the input card in question.

At each substation the sequencer in the scanner is set to the number of the cards at its substation, the maximum being four, and when called, it steps through those cards in reverse order, finishing at card 0, i.e. all substations finish their variable length transmissions at card 0.

The parity/fault bit is set to give a parity check with the data word, and if a fault is detected locally, e.g. a monitored input line is faulty, the parity bit is set to give incorrect parity so that the date is known to be corrupted.

The master station monitors the data sent from a substation and checks everything for accuracy. Thus it checks that the address is correct, that the parity bit is correct, that an end of work marker bit appears at the end of each sixteen bit work, and that card 0 has transmitted. If the first three items are correct the master station does nothing. When it detects that card 0 has transmitted it waits one clock pulse and then sends a reset pulse followed by the next address.

If the master station detects that the address or the parity bit is wrong, it carries out checking routines to establish the nature of the fault, e.g. noise or monitor fault. These routines are interlaced with the normal scan to avoid holding up data traffic. The master station may send a reset pulse to prevent the data from being acted on, or in the case of a parity error, the station for which the data word is intended may recognize the parity error and not act on the data.

If the end of word marker does not appear when it ought to, the master station sends out a reset pulse immediately after the incorrectly-placed end of word marker or the sixteenth bit of data, whichever is the first to occur. This prevents the intended recipient of the data from acting on that data.

If the master station detects that card 0 has not transmitted, then it sends a reset signal and retransmits the message. Fault routines are entered if the fault does not clear.

The output circuits 14, Figure 2, consist of cards each with four output circuits and the decoding means therefor. Nine clock pulses after a reset signal and one clock pulse after the master's end of word marker, each output card in every substation reads in the next sixteen bits of data. The first seven bits are decoded on each board and if the code matches the one selected on the card, that output is enabled. The last eight bits are then decoded to allow the output to take the state of the correct data bit.

Data transfer takes place one clock pulse after the end of the word marker, so that if the master detects a fault, the reset pulse prevents the outputs from taking up the new state of the data. If no faults are detected the output cards are read in the next sixteen data bits and reading continues until reset occurs.

We now consider the system under fault conditions, and possible fault conditions are:-

(i) Line short circuit;

(ii) Line open circuit;

(iii) Total or partial failure of a 20 substation;

(iv) Total or partial failure of the master station;

(v) Input line continuity failure;

(vi) Multiple faults

Possible effects seen on the highway when fault conditions exist are:

(a) Transmitter latch up;

(b) No response to address;

(c) No response to command or monitor input data, i.e. no output;

(d) Incorrect parity;

(e) Incorrect end of word marker;

(f) No card 0 detected;

(g) Drain of power on line device.

A *line short circuit* is seen at the master station as the combination of effects (b) and (g). The master then enters its fault detection sequence mentioned above, and eventually locates the fault. It then closes drive switches, e.g. SD1, so that the master station can transmit from the newly selected loop end, or from both loop ends, depending on where the fault is located. If, in spite of this, a substation still does not respond, it is assumed that that substation has

failed.

An *open circuited line* is seen at the master station as effect (b), as transmission in normal operation is in one direction. Again the master locates the fault and closes drive switches for normal operation. If a substation still fails to respond, it is assumed that it has failed and the drive switches on one side of the loop are opened. Here, of course, some substations may be deprived of service.

A *failure of a substation* may be seen at the master station as any of the effects listed above. In such case the master station sends out a reset pulse unless effect (g) is noted. If the fault is not cleared by the reset pulse, the master station locates and displays the fault, whereafter normal scanning is resumed. In the event of effect (g), the matter is dealt with as for a short-circuit. If the transmitter cannot be switched off by a reset pulse-effect (a) - the system totally fails until the offending unit is disabled.

Master station failure causes a master fault alarm to be generated. Hence power is removed from the master drive circuits, so that all the drive switches close. A secondary master station then assumes control. Such secondary master station can be manually switched in, or can take over automatically after data transactions have been suspended for a certain, preset, time.

Input line continuity failure is seen as effect (d), and this causes the master station to send a reset pulse. If the fault still occurs, the master station retransmits the address with a special code, using three space bits, asking for input fault status. The message received as a result of this code tells the master station where the fault is, so this fault is displayed and normal scanning is resumed.

Multiples faults. Multiple short circuits or open circuits isolate part of the line, and multiple failures at substations lose the services associated with those substations or part substations. Multiple master station failure is catastrophic, but the extent of this would depend on the number of standby master stations available, and the extent of the redundancy built in to the master station.

Multiple input line continuity failure loses the services on each line or on each faulty eight-input card.

The action produced in the case of multiple faults naturally depends on the nature of the faults, but in all cases an appropriate fault display occurs.

CLAIMS

1. A data transmission system, which includes a master station and a number of sub-stations interconnected by a data highway, in which the data is transmitted as modulations on an alternating current carrier, each data message including an appropriate address code, in which each said sub-station is capacitively coupled to the data highway, and in which data transmission over the highway can be effected in either direction.

2. A data transmission system, which includes a master station and a number of substations interconnected by a closed loop data highway, in which the data is transmitted as modulations on an alternating current carrier, in which both ends of the loop are connected to the master station, the master station interrogating the substation cyclically in search of stations with data for transmission, in which when the interrogated substation has data to be sent to another station, the message sent from the interrogated substation to convey that data includes an address code identifying the station to which that message is to be sent, in which said substation is capacitively coupled to the data highway; and in which transmission over the loop, whether for said interrogation by the master station or for the transmission of a message in response to a said interrogation, can be in either direction over the closed loop highway.

3. A system as claimed in claim 1 or 2 and in which the data highway is a two-wire highway with the two wires coupled to each said substation via capacitors on each side of the substation, so that the result is an H network wherein the substation forms the cross-piece of the H.

4. A system as claimed in claim 1, 2 or 3, and in which the data is conveyed in binary form by frequency shift keying of the carrier.

5. A system as claimed in claim 1, 2, 3 or 4, and in which the carrier frequency is in the radio frequency range so that the system is not subjected to low (i.e. mains) frequency interference.

6. A system as claimed in claim 1, 2, 3, 4 or 5, and in which a separate loop, similar to that used for the data is used to convey clock pulses to maintain synchronism in the system.

7. A system as claimed in claim 1, 2, 3, 4 or 5, and in which a separate highway similar to that used for the data is used to convey alternating current for power supply, which circuit is rectified at each said substation to produce direct current for the substation.

8. A system as claimed in claim 6 or 7, and in which either or both of the separate highways is used to convey reset pulses for resetting the system as and when required.

9. A system as claimed in claim 2 or in any claim dependent thereon, in which a short circuit on a said highway or within a substation is detected at the master station as a result of an excessive power drain together with a failure to respond to a message address, and in which the detection of a said fault causes the feed from the master station to be switched from a feed from one end of the highway to a feed from the other end of the highway.

10. A system as claimed in claim 2 or in any claim dependent thereon, and in which in the case of any fault detection the direction of message transmission on the highway is reversed.

11. A data transmission system substantially as described with reference to the accompanying drawings.

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